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THE REFRACTORY PHASE OF THE PROTECTIVE-WINK REFLEX:

The Primary Fatigue of a Human Nervous Arc

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Two considerations at least give psychological significance to the refractory phase of a human reflex. The first is its direct bearing on the problems of mental fatigue. A second is the remoter possibility of using it as a measure of recuperability.

To Professor Verworn[1] and his pupils we owe the proof that the refractory phase of nervous tissue is an elementary phenomenon of fatigue, and that in what we more commonly know as fatigue and exhaustion, the refractory phase is relatively prolonged.

Mental fatigue, if the phrase has any propriety, is a concept which implies a correlation between mental processes and processes of general physiology. But in the attempt to analyze out the psychophysical correlations of mental fatigue, psychologists have always been embarrassed by the apparent difficulty of finding anything in experience and conduct which corresponds directly with fatigue of nervous tissue. This difficulty is even more conspicuous with respect to the primary fatigue of nervous tissue, *i. e.*, its refractory phase. The immediate repetition of a simple mental process seems to be one of the easiest of mental tasks. There is certainly no obvious moment of paralysis when the immediate repetition of a simple

[1] M. Verworn, *Allgemeine, Physiologie,* Fifth Edition, 1909, 558 fol.; see also *Silliman Lectures* for 1911.

mental act is impossible. It is significant that no one has ever sought evidence of mental fatigue in repetitions of the same mathematical sum. On the contrary it is curiously customary in addition tests and other similar tests to repeat the same combinations as seldom as possible. What that means, and how constantly changing activities could ever give rise to true fatigue, are puzzling questions.

These difficulties, however, were my motive for desiring to produce and study the best possible records of the refractory phase of human reflexes. My first attempt was made on the refractory phase of the patellar reflex, demonstrated for the first time in my "Systematic exploration of a normal knee jerk." [2] Two technical difficulties showed themselves in preliminary experiments. It was found to be a mechanical difficulty to give a rapid succession of blows on the elastic patellar tendon of the same physical intensity. But there was still more serious physiological difficulty. In the knee jerk the chief reacting muscle is the quadriceps. It is probable that the stimulation occurs, not in the tendon, but in the sharp elongation of the muscle when the tendon is struck. To produce a refractory phase of the quadriceps the second stimulus must be applied to the muscle before it has entirely relaxed from the previous contraction. That means that the receptor in the two instances is not in the same condition. Finally, it is almost impossible to distinguish in the records between the mechanical effect of the blow and minute contractions of the muscle. These difficulties are probably not insurmountable, but I finally chose the protective-wink reflex because of them, and because of the simplicity and accuracy of the latter technique, in which reactor and receptor might be kept entirely separate.

The second interest attaching to the refractory phase of nervous tissue is as a test of the metabolic processes roughly designated as recuperability. In deep narcosis, extreme fatigue, and exhaustion, the refractory phase is indefinitely extended. In death its duration is infinite. In tests of neural efficiency as well as in the elaboration of a final formula for mental work it is important to have some direct technique to measure the recuperative processes in a reflex arc. From this second interest, however, we abstract entirely in the present paper.

The latent time and the duration of the several phases of the wink reaction have been investigated by a number of physiologists with a variety of different techniques. The first measurements of the latent time of the wink reflex were made

[2] *Zeitschrift für allgemeine Physiologie,* XII. 1910. 53-55.

by Exner.[3] Subsequent measurements were made by Franck,[4] Mayhew,[5] and Garten.[6]

Garten's beautiful photographic technique gave the first accurate curves of the course of the lid contraction. The recent simple and convincing kinematographic records of O. Weiss [7] unfortunately refer only to the voluntary wink and not to the protective reflex.

Both Garten and Weiss used the general principle of serial, intermittent photographic records. To give comparable values for the extremely short latent time of the reflex wink (30-50σ), such records should have a frequency of from 500 to 1000 per second. The obvious difficulties in kinematographic records of this frequency, while they are not prohibitive, emphasize the relative simplicity of my photographic method, which gives continuous records of the shadows of the eyelashes on a rapidly moving photographic plate. I believe that this will be found not only the simplest but the most accurate available technique for time measurements of the wink reflex.

The only study of the refractory phase of the wink reaction with which I am acquainted, is the classical study of Zwaardemaker and Lans.[8] Experimenting with both rabbit and human subjects, they used two forms of stimuli, flashes of light and puffs of air blown against the cornea. Both are normal, adequate stimuli for the protective wink. But they have the common disadvantage that the receptors are affected by the reaction as well as by the stimulus. The wink itself produces a sudden change in the illumination of the retina, and a slight stimulation of the cornea. Even more serious in any study of the refractory phase is the fact that, for a considerable interval of time, both receptors, the cornea and the retina, are more or less completely inaccessible to stimuli during the reflex closure of the lids.

It is commonly known that a blow on the face or a sudden noise will also produce the reflex wink. The dermal stimulus was discarded by me because preliminary experiments showed relatively long after-effects. Even the noise stimulus is not without its possible difficulties. It would be useless in case of deafness. Subjects trained by participation in athletic sports or by other means to keep their eyes open would be in a class

[3] *Pflüger's Archiv,* VIII, 1874, 526. ,

[4] Uber die zeitlichen Verhältnisse des ref. u. willk. Lidschlusses. Dissertation, Königsberg, 1889.

[5] *Jour. of exp. Medicine,* II, 1897, 35.

[6] *Pflüger's Archiv,* LXXI, 1898, 477.

[7] *Zeit. f. Sinnesphysiologie,* XLV, 1911, p. 307.

[8] *Centralblatt für Physiologie,* XIII, 1899, p. 325.

by themselves. With the deaf I have had no experience. The class would probably not be larger than that of visual defectives. Of those specially trained not to respond, I have investigated and reported one case.

The disadvantages of using the sound stimulus are not greater than those of other stimuli. The advantages of the sound stimulus are three: it permits of direct recording in the same shadow complex that includes the eye-lashes; successive stimuli are apprehended as discrete, well within the limits of completest refractory stage; the mechanism of reaction in no wise modifies the sense organ.

The Wesleyan technique for recording the reflex wink was devised by me in Verworn's Laboratory, and was published in my Systematic exploration of the normal knee jerk.[9] It has five essential factors: (1) A photographic recording device. (I naturally used my familiar falling plate recorder.) (2) A head rest to bring the shadows of the lashes perpendicularly across the slit that admits light to the photographic plate. (3) A sounding board against which a spring hammer knocks to produce the desired sound stimulus. When an offset from the sounding board casts its shadow across the aperture of the recorder, parallel to the shadow of the eye lashes, the moment of the blow is recorded with great exactness. (4) An arc light as source of illumination. (5) An oscillating marker, which is instigated by an electrically driven tuning fork, and is so placed between the arc light and the recording apparatus that the light is twice cut off in the middle of the arc of movement by every double vibration of the tuning fork.

The resulting records are shown in the figures 1-4. In reading these records one will bear in mind the following facts: The abscissae are shadows of fine silk threads. These are held before the falling plate parallel with the direction of its fall. They are spaced cr. 2mm. apart. The ordinates are the moments when the vibrating marker cuts off the light from the slit of the recording apparatus, 100 per second. All records are read from left to right as we read the printed page. The photographs are so taken that stimulus and positive reactions appear as elevations of the respective recording lines. Simultaneity of different parts of the record is guaranteed by the single source of the illumination. It is read directly by reference to the ordinates. The upper double line on each record shows the state of the sounding board. The stimulus noise, its temporal incidence, duration, and overtones are clearly recorded. The lower horizontal lines are shadows of the eye

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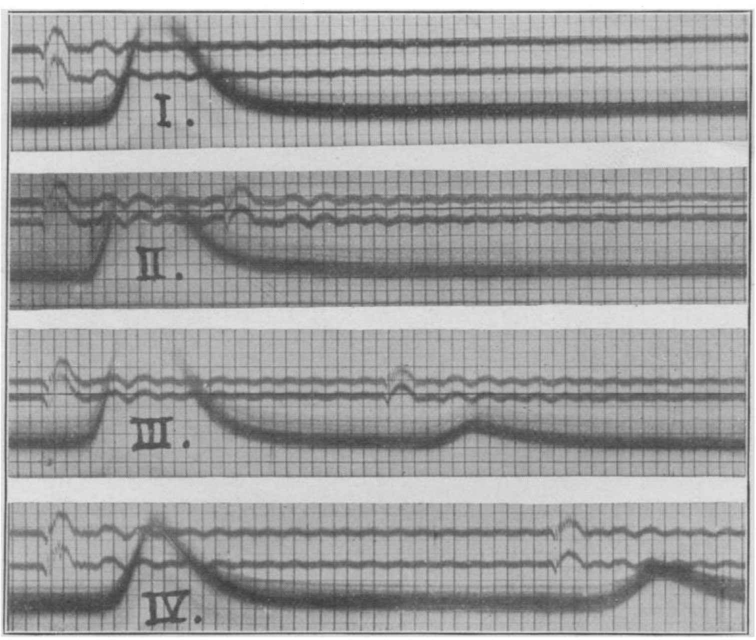
[9] *Op. cit.*


I.
II.
III.
IV.

lashes. They show the incidence, duration, and extent of the reacting lid movements.

The whole arrangement is remarkably free from instrumental errors. The registration is entirely without friction, latent time, or other common imperfections. The largest constant error is the transmission of air waves from the sounding board to the ear. But that is less than the profitable unit of measurement, which in the present plates is $1\,\sigma$. The supreme advantage of the technique is its frictionless direct action, and its sensitivity to even the smallest tremors of the lid. The slightest movements will be recorded with the same instrumental accuracy and freedom from delay as the largest.

In reading the plates two difficulties will present themselves. The first is to determine the exact moment when the shadow of the eye lashes leaves its abscissa. In actual practice this was determined by two methods: by direct magnification with a lens, and also by projection. The second difficulty will be to account for the downward preliminary stroke of the stimulus line. This downward stroke lasts approximately $5\,\sigma$. Simultaneous control records of the hammer movements and the sounding board show that the two actually meet at the lowest point of the curve. The antecedent movement in the curve is produced by the "give" of the whole sounding board system, when the hammer was electrically released. The release of the hammers was noiseless. It was accomplished by breaking the circuit of the electro-magnets that held the hammers.

In my previous paper I published data only on the latent time of the protective-wink reflex. The present records do not materially modify those data. Five subjects with cr. 10 records each gave extreme records of 28σ and $47\,\sigma$, and a mean of $30\,\sigma$. It was significant that the latent time of the low records, within the relative refractory phase, averages only slightly longer than that of the primary reactions. It seems not improbable that the entire difference is a matter of reading, due to the slower initial movement away from the abscissa. This is an important matter but at present I see no way of determining it with entire satisfaction.

The present records confirm our earlier data. The protective-wink has a very low latency for a true reflex. The longer latent periods of earlier investigators may be due in part to differences in the reflex arc. Part of the difference is undoubtedly due to their use of less delicate recording devices.

Our records of the refractory phase of the protective-wink are very different from those given by Zwaardemaker and

Lans. They found an absolute refractory phase of about 500σ in duration.

Stimuli from 500σ to 700σ apart gave double reactions in 34% of the cases.

Stimuli from 750σ to 1000σ apart gave double reactions in 67 % of the cases.

Stimuli from 1000σ to 1250σ apart gave double reactions in 100% of the cases.

My records on the contrary show no absolute refractory phase. In all my subjects a second wink was elicited by a stimulus that both the subjective apprizement and the records show to have been no more intense than the first, within 300σ of the initial stimulus. In all cases within 2σ, however, the second reaction was lower than the first. Even when, as in Fig. 2, the second stimulus occurs before the lid has reached its original abscissa, after an interval of less than 160σ, the refractory phase is not absolute. To be sure the reaction consists only in a slight hesitation of the descending limb of the curve. But this hesitation clearly differentiates record 2 from all natural returns. A less delicate technique would have missed it entirely. By comparison with the normal returns in the other figures, the reaction is unmistakable, and its apparent latent time is only slightly longer than that of the primary reaction.

Such fundamental differences between our records and the classical work of Zwaardemaker and Lans demand critical scrutiny. Our results are neither more nor less reliable, merely because they are recent. The whole matter of credibility hinges on the reliability of the respective techniques. I believe my records speak for themselves.

This is no place to discuss in detail the bearing of these differences on the general problems of primary fatigue in mental life. But it is obvious that the implications of a prolonged relative decrease in sensitivity are entirely different from the implications of a complete refractory phase, a moment of complete paralysis.

In the light of our records, the refractory phase of the nervous arc does not lead us to expect an elementary mental fatigue phenomenon of a definite absolute incapacity to repeat an act. We have no right to expect that it will operate to close absolutely a single avenue of reaction, or necessarily to increase the time of any relatively simple process. We must rather expect it to appear as a more or less pronounced tendency not to repeat a mental act, requiring a constantly in-

creasing stimulus for producing continued rapid repetitions of the same mental act, and tending to delay their succession with stimuli of the same intensity.

These tendencies certainly do exist in our mental life. They deserve to be traced with care, not merely in the matter of delay of repetition, but with respect to the relationship of all the various factors of the complex. They bear the marks of a phenomenon of real mental fatigue.

In much the same way that Sherrington indicated that fatigue operated to save the sense organs from hypertrophy, probably mental fatigue saves our mental life from monotony and the over-development of specific functions.